Vol. 01, Iss. 3 (2023) 121-130, DOI: 10.61552/JME.2023.03.005

JME

Journal of Materials and Engineering

www.jme.aspur.rs

Research article

Effect of Shaft Speed, Crack Depth and L/D Ratio in Rotor Bearing System: Using Taguchi Method and ANOVA

Sudheer Kumar Veernapu[a,b,*], Nagaraju Cherukuri[b], Vangipurapu Bapi Raju[b]

[a]*Institution or Company, Address, State.- 1Aacharya Nagarjuna University, Nagarjuna Nagar, Guntur, Andhra Pradesh, India-522510,*
[b]*Velagapudi Rama Krishna Siddhartha Engineering College, Kanuru, Vijayawada, Krishna District, Andhra Pradesh, India-520007.*

Keywords:

ANOVA
FFT Analyzer (Fast Fourier Transform analyzer)
Artificial crack
S/N ratio

* Corresponding author:

Sudheer Kumar Veernapu
E-mail: sudheer@vrsiddhartha.ac.in

Received: 20 March 2023
Revised: 12 April 2023
Accepted: 24 April 2023

A B S T R A C T

Vibration is produced by imbalance, positioning, mechanical softness, shaft cracking, and various defects in spinning machinery. In recent years, rotor defect diagnostics have become more important. This study looks at the effects of various input parameters, such as shaft operating speed, crack depths, and l/d ratio (ratio of the distance of crack from one end to the diameter of the shaft). A steel shaft with a disc positioned in the center and supported by two bearings was utilized to investigate the vibration characteristics of a shaft. An artificial fracture was introduced in order to notice the rotor's vibration characteristics when a defect is present. On a rotor with a diameter of 25mm, the signature knowledge was first obtained with fracture depths ranging from 1mm to 3mm. The amplitude and frequency of vibration in the rotor bearing system were used to analyse the results of the three input parameters. FFT analyzer was used to measure the amplitude and frequency (Fast Fourier remodel analyzer). The signals are processed using a high-speed fast Fourier remodel analyzer. To evaluate important input parameters affecting system vibrations, Taguchi and Analysis of Variance (ANOVA) methods were applied. The ANOVA was distributed with a 95% confidence level. The technique parameters with a p-value of less than 0.05 were mentioned as being critical to the response. Taguchi Analysis was used to determine the effect of the input parameters on the amplitude and frequency of vibration in the axial and vertical directions.

1. INTRODUCTION

The paper must be written in correct English In many industrial applications, bearings are the crucial mechanical components as they are proven to be most reliable and long-lived if they are properly installed. Bearings are being placed where applications need larger loads, faster rotational speeds, and lubrication limits for bearing materials, lubrication technology, design parameters, and service life improvements. As a result of these requirements, condition monitoring and fault detection in bearings have become critical for the safe functioning of rotary systems. The use of condition monitoring to prevent bearing failures is one of the most heavily investigated subjects in the mechanical engineering industry in recent decades. These studies led to a greater knowledge of bearing condition analysis as well as advancements in bearing diagnostic procedures. Methods based on vibrational analysis are regarded to be the most successful of all bearing condition monitoring technologies. As a result, vibrational analysis is applied in this research. A Vibrational analysis is carried out using characteristics extracted from a sensor signal as well as features associated with non-faulty or defective bearing components. Advances in capacity and reduction in the cost of computers enabled the advanced signal processing and analysis methods that are developed for the improvement of bearing condition monitoring.

Factorial design, response surface methodology (RSM), and Taguchi approaches are commonly utilized in place of the one factor at a time experimental approach. Taguchi approaches have been widely used for process optimization in material processing, as indicated in [1-10]. For example tool life was determined by measuring surface roughness, the amplitude of work piece vibration, and the quantity of metal removed using Taguchi, ANOVA, and Regression analysis. [1].

The effects of drilling factors namely spindle speed, helix angle, and feeds on floor roughness, flank wear, and drill vibration was studied by Balaji et al. [2] using the response surface approach. To optimize the drilling factors for decreased floor roughness, flank wear and drill vibration, a multi-response optimization approach was used by the authors. Chandrasekaran et al. [11] and Muthu et al. [12] additionally revealed that the feed has a greater effect on the floor roughness. Confirmation experiments were also carried out to ensure that the ultimate outcome was correct. The most important values of manage factors were computed using S/N analysis and suggested response qualities [3]. Taguchi invented positive preferred arrays, which allowed the simultaneous and impartial evaluation of several factors in the same space. In comparison to traditional design techniques, the arrays have been constructed in such a way that the number of trials has been kept to a minimum. [4]. Bala et al. [13] used this technique at the side of Taguchi in optimizing factors in the machining of hard metal.

The Taguchi approach is a useful tool for analysing engineering designs. It consists of a set of experimental designs with certain goals in mind, such as gathering information in a definite method and generating data about reaction for a specific procedure. This approach allows for fewer trials to be conducted, lowering the cost and duration of the studies. The plan is processed using orthogonal arrays, and the final findings are established on average examination and also ANOVA. Through appropriate process factors, the Taguchi approach is commonly utilised to determine numerous research, such as optimal deposited coating parameters and tribological qualities.

The Taguchi approach was utilised by Mahapatra et al. [14] to assess the erosive wear rate of polyester composites reinforced with various E-glass fibres. The testing results showed that solid erodent particles had a greater influence on erosive wear rate. Bushroa et al. [15] employed the Taguchi technique to investigate the influence of load, area density, and sliding speed on the friction function of WC/C cemented carbide texture. The area density of textures is verified to play a significant impact on the mean coefficient of friction and wear rate. The L9 Taguchi orthogonal array approach was used to define the coating deposited procedures on high-speed steel and to assess the impact of cutting parameters on surface roughness. The results suggested the critical load had a greater impact on deposited coating thickness, with feed rate having the most significant effect [16, 17].

A typical orthogonal array L9 Taguchi approach and regression analysis were used to find the best machinability parameters such as cutting speed, feed rate, and depth of cut for newly designed Zirconia toughened alumina ceramic inserts with AISI-4340 steel [18]. Taguchi L9 runs of DOE was used, the S/N ratio was governed by means of smaller the higher criterion, and the ANOVA was used to find the significant factors such as lowering velocity, feeds, and cut depths. The factor optimization was also carried out with a 95% confidence level. Using surface roughness, RMS of work piece vibrations, and machining period of time till the tool distorted, ANOVA was also performed to determine the influence of lowering speeds, nose radii, and feeds [13].

In this work, an artificial crack was introduced to determine the effect of a defect in the shaft. Initially, the signature data was obtained with crack depths ranging from 1mm to 3mm on the rotor of 25mm diameter. The effects of input parameters were analyzed by evaluating the amplitude and Frequency of vibration in the rotor bearing system. The amplitude and frequency were measured using FFT Analyzer (Fast Fourier Transform analyzer). A high-speed Fast Fourier Transform analyzer is used to process the signals. Taguchi and Analysis of Variance methods were used to identify significant input parameters affecting the system vibrations and the input parameters are optimized using S/N ratios of the experiments.

2. EXPERIMENTAL PROCEDURE

The experimental setup consisted of a steel shaft supported on two bearings at both ends (Fig. 1) and having a disc in the center: The shaft diameter is 25mm, the length is 400mm, and the disc mass is 1.2 kilogram. The FFT analyzer, which can detect velocities of up to 200 mm/sec with a resolution of 0.1 mm/sec and a frequency range of 10-1 KHz, was used. The rotor is given a 1500 rpm input with varying fracture depth. The statistics about the sensor's setup and position are supplied to the computer and then passed to the FFT analyzer. The collected data from the FFT analyzer is then sent to the computer to generate the wave shapes. Figure 2 depicts amplitude spectrums for bearing 1 in the vertical direction at 3mm fracture depth, 1000rpm shaft rotation speed, and L/D ratio1.6.

Fig. 1. FFT analyzer connected with rotor setup.

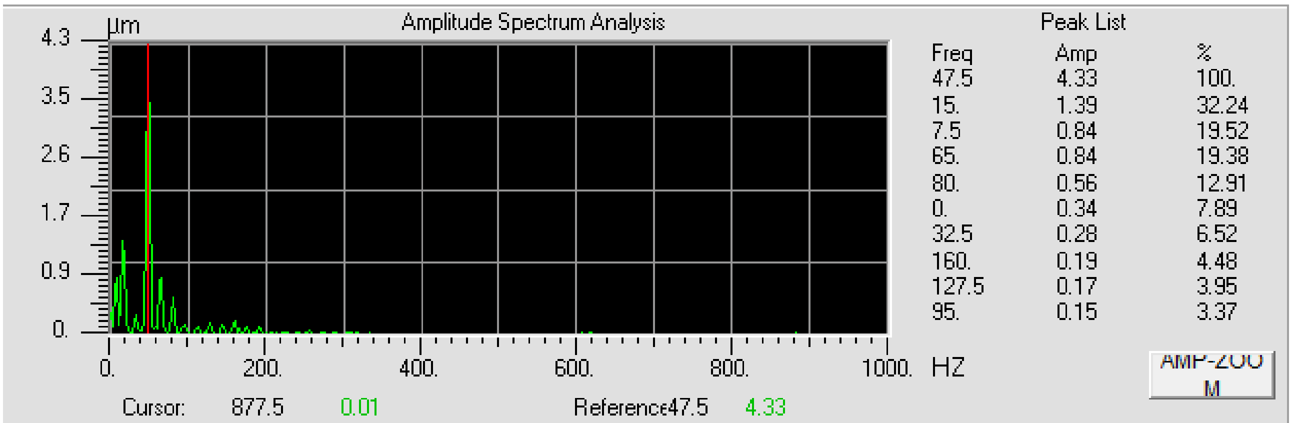

Fig. 2. Spectrum at 1000rpm for bearing 1 crack depth 3 mm, L/D ratio 1.6 in vertical direction.

The Taguchi technique was used to study the effect of L/D ratio, Shaft speed, and fracture depth on the amplitude and frequency of vibration. As indicated in Table 1, the experimental data was analysed using the smaller the better features since the aim of the current analysis is to decrease the amplitude and frequency of the bearing vibration.

The amplitude and frequency of two bearings vibration in two directions, axial and vertical, were investigated. Using experimental data, the Taguchi technique computed delta values for input parameters such as L/d ratio, shaft speed, and fracture depth. The suggested technique ranked the input parameters based on the bigger delta value.

The L/D ratio was shown to have a considerable effect on the amplitude and frequency of vibration in both directions.

Taguchi technique was used to assess experimental data of amplitude and frequency of two bearings vibration in axial, horizontal, and vertical directions. Signal-to-noise ratios for vibration amplitude and frequency are computed and examined utilizing the smaller the better features. Table 1 displays a study of the signal-to-noise ratios and major parameters influencing the responses. According to the delta values, shaft velocity has the highest delta value, followed by the L/D ratio and fracture depth. As a result, shaft speed was discovered to be the most important of the three parameters. Similarly, the L/D Ratio has a large delta value, followed by shaft speed and crank depth.

ANOVA is a widely used approach for analysing responses or experimental data in a variety of applications. The ANOVA was performed with a 95% confidence level. Process parameters with p-values less than 0.05 were considered significant in the response. Furthermore, the input parameters should have F values greater than four.

Table 1. Bearing 1 response data.

AMPLITUDE IN AXIAL DIRECTION, A_A					**FREQUENCY IN AXIAL DIRECTION, F_A**			
Level	L/D Ratio	Shaft Speed	Crack Depth		Level	L/D Ratio	Shaft Speed	Crack Depth
1	-10.057	-5.641	-9.380		1	-17.40	-14.38	-17.15
2	-8.294	-8.581	-10.299		2	-20.44	-16.50	-17.13
3	-5.022	-12.861	-7.405		3	-15.13	-20.56	-17.33
4	-10.645				4	-32.04		
5	-10.381				5	-19.04		
6	-10.272				6	-13.08		
7	-8.523				7	-15.87		
Delta	7.220	5.623	2.894		Delta	18.96	6.18	0.20
Rank	1	2	3		Rank	1	2	3
AMPLITUDE IN VERTICAL DIRECTION, A_V					**FREQUENCY IN VERTICAL DIRECTION, F_V**			
Level	L/D Ratio	Shaft Speed	Crack Depth		Level	L/D Ratio	Shaft Speed	Crack Depth
1	0.7383	1.8705	-1.8369		1	-29.35	-19.07	-24.70
2	-2.4546	-2.4838	-3.1190		2	-24.54	-25.45	-25.50
3	-1.7772	-5.8898	-1.5472		3	-18.43	-25.29	-19.61
4	6.3563				4	-19.33		
5	-5.4682				5	-28.48		
6	-6.7506				6	-20.39		
7	-5.8179				7	-22.38		
Delta	13.1069	7.7604	1.5717		Delta	10.92	6.38	5.90
Rank	1	2	3		Rank	1	2	3

3. RESULTS AND DISCUSSION

3.1 Effect of input parameters on the amplitude of vibration in axial direction

Regression equations for two bearings are obtained as follows from Taguchi analysis:

Regression Equation in uncoded Units for Bearing 1

$$\begin{aligned} AA &= 1.89 - 0.621\, L/D + \\ &+ 0.00319\, S S + 0.73\, C D + 0.0473\, L/D*L/D + \\ &+0.000001\, S S*S S- 0.358\, C D*C D - \\ &-0.000398\, L/D*S S + 0.0301\, L/D*C D + \\ &+0.000700\, S S*C D \end{aligned} \quad (1)$$

Regression equation in uncoded units for Bearing 2 is obtained as mentioned below

$$AA = -4.31 + 0.243\ L/D + 0.0142\ S\ S + 2.38\ CD - 0.0154\ L/D*L/D - 0.000007\ S\ S*S\ S - 0.588\ CD*CD - 0.000193\ L/D*S\ S + 0.020\ L/D*CD - 0.00053\ S\ S*CD \quad (2)$$

From the analysis of variance for the amplitude of vibration in the axial direction, it is clear that the L/D ratio and shaft velocity have a significant effect on the amplitude of vibration in the axial direction. It was observed that p value is less than 0.05 and F value is greater than 4 for these input parameters ANOVA data on one of the bearings is presented in Table 2.

Table 2. Analysis of Variance for Amplitude of vibration in axial direction bearing 1.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	97.743	10.8603	10.21	0.000
Linear	3	82.380	27.4599	25.83	0.000
L/D	1	48.304	48.3044	45.43	0.000
S S	1	34.074	34.0740	32.05	0.000
C D	1	0.001	0.0012	0.00	0.974
Square	3	10.413	3.4708	4.26	0.028
L/D*L/D	1	8.570	8.5696	8.06	0.006
S S*S S	1	0.048	0.0476	0.04	0.833
C D*C D	1	1.795	1.7953	1.69	0.199
2-W I	3	4.950	1.6502	1.55	0.212
L/D*S S	1	3.750	3.7501	3.53	0.066
L/D*C D	1	0.343	0.3429	0.32	0.572
S S*C D	1	0.857	0.8575	0.81	0.373
Error	53	56.351	1.0632		
Total	62	154.093			

3.2 Effect of input parameters on the amplitude of vibration in axial direction

Regression equations for two bearings are obtained as follows from Taguchi analysis:

Regression Equation in Uncoded Units for Bearing 1

$$AV = 2.97 - 0.077\ L/D - 0.00743\ S\ S - 0.32\ C\ D - 0.0005\ L/D*L/D + 0.000005\ S\ S*S\ S - 0.150\ C\ D*C\ D + 0.000301\ L/D*S\ S - 0.0029\ L/D*C\ D + 0.001509\ S\ S*C\ D \quad (3)$$

Regression Equation in Uncoded Units for Bearing 2

$$AV = 2.85 - 0.050\ L/D - 0.00484\ S\ S + 0.81\ CD + 0.0196\ L/D*L/D + 0.000002\ S\ S*S\ S - 0.107\ CD*CD - 0.000069\ L/D*S\ S - 0.1177\ L/D*CD + 0.000732\ S\ S*CD \quad (4)$$

From the analysis of variance for the amplitude of vibration in the vertical direction it is clear that the L/D ratio and shaft velocity have a significant effect on the amplitude of vibration in the vertical direction. It was observed that p value is less than 0.05 and F value is greater than 4 for these input parameters

ANOVA data on one of the bearings is presented in Table 3.

3.3 Effect of input parameters on the frequency of vibration in axial direction

Regression equation for two bearings are obtained as follows from Taguchi analysis.

Regression Equation in Uncoded Units for Bearing 1

$$FA = 18.3 - 7.93\ L/D + 0.001\ S\ S + 6.0\ C\ D + 0.265\ L/D*L/D + 0.000015\ S\ S*S\ S + 0.36\ C\ D*C\ D + 0.00782\ L/D*S\ S + 0.040\ L/D*C\ D - 0.0154\ S\ S*C\ D \quad (5)$$

Regression Equation in Uncoded Units for Bearing 2

FA = 35.4 - 0.21 L/D - 0.063 S S-
- 4.5 CD + 0.175 L/D*L/D + 0.000036 S S*S S-
-0.12 CD*CD - 0.00136 L/D*S S-
- 0.55 L/D*CD + 0.0115 S S*CD (6)

From the analysis of variance for frequency of vibration in the axial direction, it is clear that L/D ratio and crack depth have a significant effect on the frequency of vibration in the axial direction. It was observed that p value is less than 0.05 and F value is greater than 4 for L/D ratio but less than 4 for the crack depth.

ANOVA data on one of the bearings is presented in Table 4.

Table 3. Analysis of Variance for amplitude of vibration in vertical direction (bearing 1).

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	66.084	7.3427	8.69	0.000
Linear	3	58.518	19.5059	23.08	0.000
L/D	1	10.726	10.7260	12.69	0.001
S S	1	46.179	46.1791	54.64	0.000
C D	1	1.613	1.6127	1.91	0.173
Square	3	1.441	0.4802	0.57	0.638
L/D*L/D	1	0.001	0.0008	0.00	0.975
S S*S S	1	1.124	1.1239	1.33	0.025
C D*C D	1	0.316	0.3160	0.37	0.543
2-W I	3	6.126	2.0419	2.42	0.077
L/D*S S	1	2.140	2.1398	2.53	0.118
L/D*C D	1	0.003	0.0033	0.00	0.951
S S*C D	1	3.983	3.9826	4.71	0.034
Error	53	44.793	0.8451		
Total	62	110.877			

Table 4. Analysis of Variance for frequency of vibration in axial direction (bearing 2).

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	529.5	58.831	0.25	0.000
Linear	3	101.9	33.952	0.14	0.000
L/D	1	21.9	21.854	0.09	0.007
S S	1	75.2	75.195	0.31	0.057
C D	1	2.7	2.686	0.01	0.016
Square	3	161.1	53.708	0.22	0.879
L/D*L/D	1	81.2	81.172	0.34	0.562
S S*S S	1	68.9	68.870	0.02	0.594
C D*C D	1	0.2	0.182	0.00	0.017
2-Way Interaction	3	294.0	98.008	0.41	0.746
L/D*S S	1	40.7	40.743	0.01	0.681
L/D*C D	1	67.1	67.113	0.28	0.598
S S*C D	1	207.1	207.069	0.87	0.356
Error	53	12659.4	238.857		
Total	62	13188.9			

3.4 Effect of input parameters on the frequency of vibration in vertical direction

Regression equation for two bearings are obtained as follows from Taguchi analysis.

Regression Equation in Uncoded Units for bearing 1

FV = 49.5 - 8.91 L/D - 0.015 S S +
+12.2 C D + 0.515 L/D*L/D + 0.000005 S S*S S-
-5.05 C D*C D - 0.00036 L/D*S S +
+0.67 L/D*C D + 0.0050 S S*C D (7)

Regression Equation in Uncoded Units for bearing 2

FV = 57.1 - 5.24 L/D - 0.107 S S +
+ 21.8 CD+ 0.269 L/D*L/D + 0.000086 S S*S S-
-9.70 CD*CD - 0.00168 L/D*S S +
+1.66 L/D*CD+ 0.0013 S S*CD (8)

From the analysis of variance for frequency of vibration in the vertical direction, it is clear that shaft speed and crack depth have somewhat effect on the frequency of vibration in the vertical direction. It was observed that p value is less than 0.05 but F value is less than 4 for these input parameters ANOVA data on one of the bearings is presented in Table 5.

Table 5. Analysis of Variance for frequency of vibration in vertical direction (bearing 1).

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	4946.1	549.57	1.31	0.254
Linear	3	1621.5	540.50	1.29	0.288
L/D	1	0.4	0.44	0.00	0.974
S S	1	531.2	531.23	1.27	0.026
CD	1	1021.6	1021.57	2.43	0.012
Square	3	2105.4	701.80	1.67	0.184
L/D*L/D	1	190.7	190.66	0.04	0.503
S S*S S	1	400.6	400.59	0.95	0.333
CD*CD	1	1149.5	1149.51	2.74	0.010
2-Way Interaction	3	641.1	213.70	0.51	0.678
L/D*S S	1	62.2	62.22	0.01	0.702
L/D*CD	1	599.2	599.22	1.43	0.023
S S*CD	1	2.8	2.83	0.01	0.935
Error	53	22246.6	419.75		
Total	62	27192.7			

3.5 Analysis of S/N ratio of input parameters on the amplitude of vibration in axial direction

The effect of S/N ratios on the amplitude of vibration for both the bearings in the axial direction is shown in Figures 3 and 4. From these figures, it can be concluded that the amplitude of vibration in the axial direction will be minimum when the crack is in the middle (L/D ratio around 8). As expected as the speed increases the amplitude of vibration increases. Similarly, the amplitude becomes very sensitive to crack depth when its value crosses 2mm.

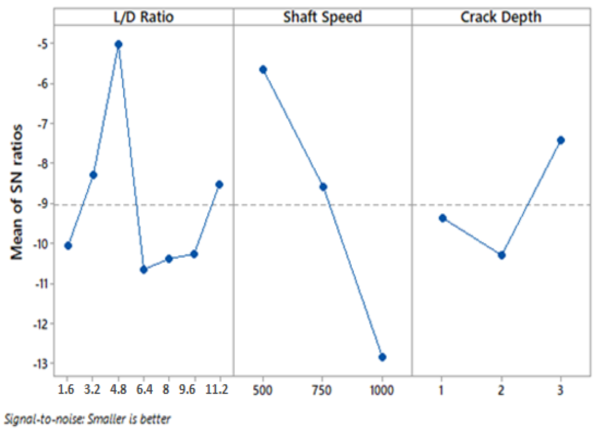

Fig. 3. Effect of inputs on amplitude of vibration in axial direction for Bearing 1.

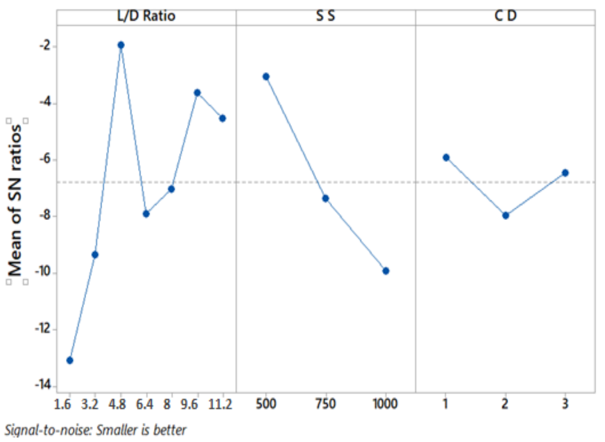

Fig. 4. Effect of inputs on amplitude of vibration in axial direction for bearing 2.

3.6 Effect of inputs parameters on the amplitude of vibration in vertical direction

The effect of S/N ratios on the amplitude of vibration for both the bearings in vertical direction is shown in Figure 5 and 6. From these figures it can be concluded that amplitude of vibration in vertical direction will be minimum when the crack is in the middle (L/D ratio around 8). As expected as the speed increases the amplitude of vibration increases. Amplitude in vertical direction is not impacted significantly at least for smaller crack depths.

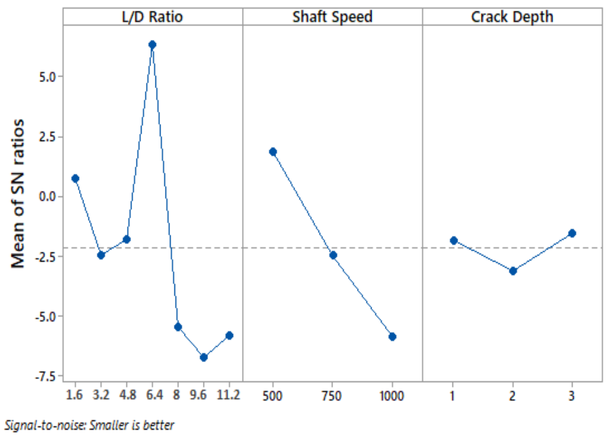

Fig. 5. Effect of inputs on amplitude of vibration in vertical direction for bearing 1.

3.7 Effect of inputs on input parameters for the frequency of vibration in axial direction

The effect of S/N ratios on the frequency of vibration for both the bearings in the axial direction is shown in Figures 7 and 8. From these figures, it can be concluded that the frequency of vibration in the axial direction will be minimum when the crack is in the middle (L/D ratio around 8). As expected as the speed increases the frequency of vibration increases. Frequency in the axial direction is not impacted significantly at least for smaller crack depths.

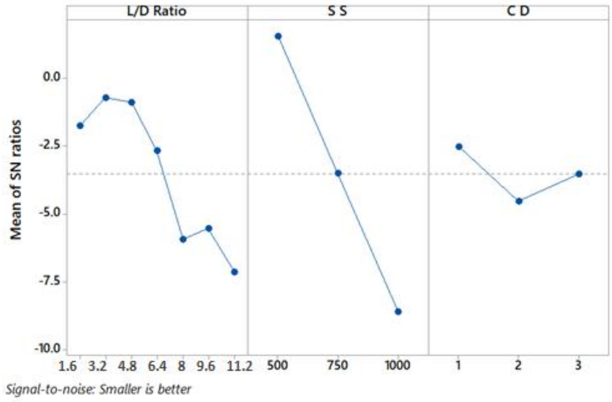

Fig. 6. Effect of inputs on on amplitude of vibration in vertical direction for bearing 2.

3.8 Effect of input parameters for the Frequency of Vibration in vertical direction

The effect of S/N ratios on the frequency of vibration for both the bearings in the vertical direction is shown in Figures 9 and 10. From these figures, it can be concluded that the frequency of vibration in the vertical direction will be minimum when the crack is in the middle (L/D ratio around 8).

As expected as the speed increases the frequency of vibration increases. Frequency in the vertical direction is not impacted significantly at least for smaller crack depths.

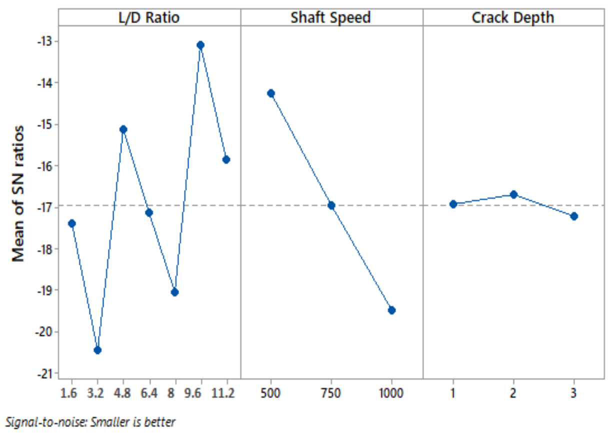

Fig. 7. Optimization of inputs for frequency of vibration in axial direction for bearing 1.

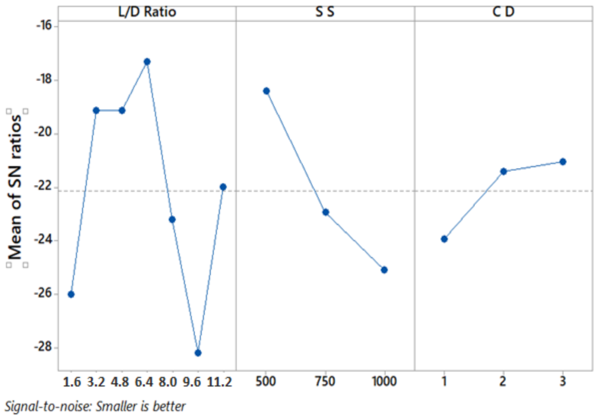

Fig. 8. Effect of inputs on frequency of vibration in axial direction for bearing 2.

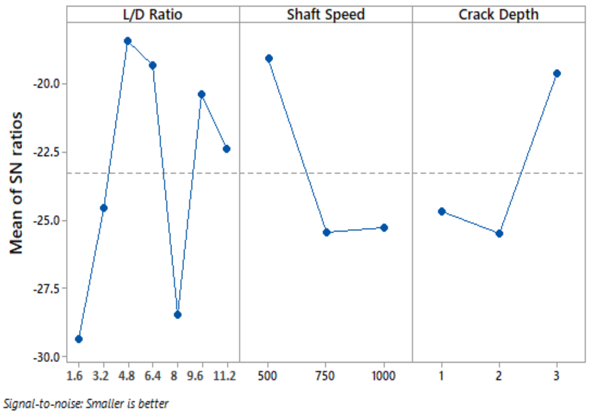

Fig. 9. Effect of inputs on frequency of vibration in vertical direction for bearing 1.

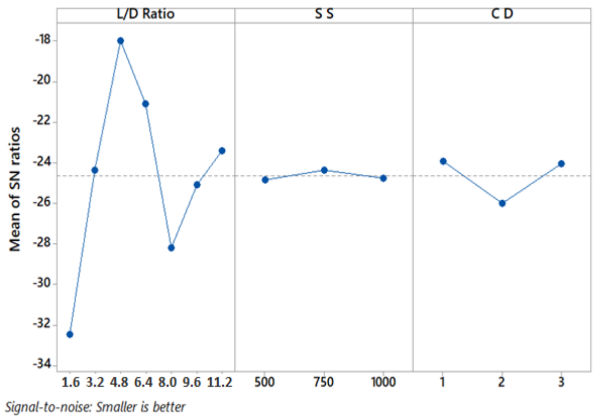

Fig. 10. Effect of inputs for frequency of vibration in vertical direction for bearing 2.

Overall it can be concluded that the location of the crack and the shaft speed have a significant effect on the amplitude of the vibration in both axial and vertical directions. As far as the frequency of vibration is concerned only the location of the crack has a significant effect that too in the axial direction.

The adverse effect of the amplitude and frequency of vibration of the crack will be less when the crack is located centrally and shaft speed is low and the crack depth is low.

4. CONCLUSION

Experiments were carried out on a shaft held between two bearings at various degrees of fracture depth, location, and shaft speed in the current study. The experimental findings of vibration amplitude and frequency in vertical and axial directions were evaluated for both bearings. Using taguchi analysis it was found that the location of the crack (L/D) plays a dominant role in increasing the amplitude and frequency of the vibration. Next shaft speed plays an important role in increasing the amplitude. At least for small values the crack depth plays comparatively less role. The future studies can focus on the effect of the amplitude and frequency when the crack depth increases to a larger value.

REFERENCES

[1] K. Venkatarao, B.S.N. Murthy, and N. Mohan Rao, "Cutting tool condition monitoring by analyzing surface roughness, work piece vibration and volume of material removed for AISI 1040 Steel in boring," *Int. J. of Meas*, vol. 46, pp. 4075-084, 2013.

[2] M. Balaji, K. Venkat Rao, B.S.N. Murthy, and N. Mohana Rao, "Optimization of milling parameters for drilling of TI-Al-4V based on roughness, flank wear and drilling vibration," *Int. J. of Meas*, vol. 114, pp. 332-339, 2018.

[3] H. Singh and P. Kumar, "Tool wear optimization in turning operation by Taguchi method," *Indian J. Eng. Mater. Sci*, vol. 11, pp. 019-024, 2004.

[4] G. Taguchi, "Introduction to Quality Engineering," Asian Productivity Organization (APO), Tokyo, Japan, vol. 16, 1990.

[5] W.H. Yang and Y.S. Tarng, "Design optimization of cutting parameters for turning operations based on the Taguchi method," *J. Mater. Process. Technol*, vol. 84, pp. 122-129, 1998.

[6] Y.L. Su, S.H. Yao, C.S. Wei, W.H. Kao, and C.T. Wu, "Design and performance analysis of TiCN-coated cemented carbide milling cutter," *J. Mater. Process. Technol*, vol. 87, pp. 82-89, 1999.

[7] C.Y. Nian, W.H. Yang, and Y.S. Tarng, "Optimization of turning operations with multiple performance characteristics," *J. Mater. Process. Technol*, vol. 95, pp. 90-96, 1999.

[8] T.R. Lin, "Experimental design and performance analysis of TiN coated carbide tool in face milling stainless steel," *J. Mater. Process. Technol*, vol. 127, pp. 01-07, 2002.

[9] J.P. Davim, "Design optimization of cutting parameters for turning metal matrix composite based on the orthogonal arrays," *J. Mater. Process. Technol*, vol. 132, pp. 340-344, 2003.

[10] J.A. Ghani, I.A. Choudhury, and H.H. Hassan, "Application of Taguchi method in the optimization of end milling operation," *J. Mater. Technol*, vol. 145, pp. 84-92, 2004.

[11] P. Marimuthu and K. Chandrasekaran, "Experimental study on stainless steel for optimal setting of machining parameters using Taguchi and neural network," *Arpn J. Of Eng. and App. Sci*, vol. 6, pp. 119-127, 2011.

[12] N. Muthukrishnan and J. Paulo Davim, "Optimization of machining parameters of Al/SiC-MMC with ANOVA and ANN analysis," *J. of Mats Proc. Technol*, vol. 209, pp. 225-232, 2009.

[13] B.M. Gopalsamy, B. Mondal, and S. Ghosh, "Taguchi method and ANOVA: An approach for process parameters optimization of hard machining while machining hardened steel," *J. of Sci. and Indl. Research*, vol. 68, pp. 686-695, 2009.

[14] S.S. Mahapatra, A. Patnaik, and A. Satapathy, "Taguchi method applied to the parametric appraisal of the erosion behavior of GF-reinforced polyester composites," *Wear*, vol. 265, pp. 214-222, 2008.

[15] A.R. Bushroa, H.H. Masjuki, M.R. Muhamad, and B.D. Beake, "Optimized scratch adhesion for TiSiN coatings deposited by a combination of DC & RF sputtering," *Surf. Coat. Technol*, vol. 206, pp. 837-844, 2011.

[16] A. Satapathy, A. Patnaik, and M.K. Pradhan, "A study on processing, characterization and erosion behavior of fish scale filled epoxy matrix composites," *Mater. Des*, vol. 30, pp. 2359-371, 2009.

[17] Asilturk and H. Akkus, "Determining the effect of cutting parameters on surface roughness in hard turning using the Taguchi method," *J. Meas*, vol. 44, pp. 1697-704, 2011.

[18] N. Mandal, B. Dolai, B. Mondal, and R. Das, "Optimization of Flank wear Zirconia toughened alumina (ZTA) cutting tool: Taguchi method and regression analysis," *Intl. J. of Meas*, vol. 44, pp. 2140-155, 2011.